Source Term Balance For Finite Depth Wind Waves

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LONG-TERM GOAL

The long-term goal is to obtain closure of the energy balance equation for wind wave evolution in finite depth water by means of direct measurement of the main source terms. These source terms represent the basic physical processes required to develop reliable finite depth wave prediction models.

SCIENTIFIC OBJECTIVES

The objectives are to establish a description of the basic sources/sinks of energy responsible for shallow water wind wave evolution, namely dissipation due to both wave breaking and bottom friction, and wind input. Spectral distribution of "white-capping" dissipation has not previously been obtained either experimentally or theoretically, and currently speculative approaches are used to represent this term in wave models. The natural phenomena determining this term are random, non-linear and related to extreme wave conditions and hence are difficult to evaluate in the field. The other two terms have been the subjects of intensive research during the last three decades, although detailed field observations are rare. There is a qualitative understanding of their behaviour, however, no established quantitative description is available.

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APPROACH

An integrated set of measurements in the atmospheric and sub-surface boundary layers as well as on the surface itself has been carried out at the Lake George field experimental site for the last two years, whenever meteorological forecasts were appropriate. In August - September, 1999, the end of the Southern Hemisphere winter and a time of regular cross-lake winds, an intensive observation period was conducted. The previous measurements were supplemented by fine-scale measurements of wave-induced pulsations of air pressure, sub-surface turbulence and bottom boundary layer velocity profiles. This latter experiment, jointly conducted with two American groups, was titled AUSWEX (Australian Shallow Water Experiment).

Lake George is a shallow water basin and closely approximates the idealised case of finite depth, fetch limited growth. The experimental site includes an observational platform with a shelter to accommodate electronics and equipment as well as researchers during observations. An anemometer mast, accommodating 3 wind probes at 10 m and 5.65 m elevations over the water surface, was erected 10 m from the platform. Another anemometer mast, accommodating 5 wind probes at four heights closer to the surface, was set 6 m off the bridge to ensure undisturbed airflow for these lower anemometers. The bridge was used for the majority of the wave measurements. Two shelters constructed onshore provided basic storage and accommodation for researchers during their stay at the site. The location has vehicular access, a simple offshore bathymetry and water of approximately 0.5 m depth within 50 m of the shoreline, ideal for the objectives of the shallow water study. The platform, located approximately 50 m offshore is shore-connected with an elevated walkway and is thus accessible in any weather conditions. Computer facilities allowed for preliminary data analysis to be performed on site, though the main data processing was conducted at the Australian Defence Force Academy (ADFA). The site is located approximately one hours drive from ADFA.

To measure "white-capping" dissipation, four different but integrated instrument systems were employed. Since individual waves naturally change their heights whilst propagating within irregular wind wave groups, direct in situ estimates of energy lost by breaking were obtained in terms of the integrated group energy, measured with an array of capacitance wave probes. The array also allowed measurement of directional wave spectra. Two additional mobile wave probes were positioned to measure spatial decay of breaking wave groups. An observer also marked data records electronically, in response to visual observations of breaking. Facilities for quick in situ calibrations of the wave probes were available. Three Acoustic Doppler Current Meters (ADV) were employed for simultaneous measurement of dissipation rates through the water column in the vicinity of the array. During AUSWEX, these measurements of the turbulence were supplemented by "Dopbeam" measurements of wave-number velocity spectra. The Dopbeam was provided by Kendall Melville of the Scripps Institution of Oceanography, USA for the period of the experiment. An underwater hydrophone, the output of which is related to both the strength and dimension of breakers, was located on the bottom beneath the array. Video recording of the surface spot around the array was used to identify breaking events and to supply information on the spatial dimensions of white-capping. The logging of all systems was synchronised.

Simultaneously, measurements in the atmospheric boundary layer were also conducted. The anemometer masts have six cup anemometers logarithmically spaced from 0.5 m to 10 m and two wind direction vanes. The data logging was synchronised with the wave and breaking recordings. In addition to the wind profile measurements, a sonic anemometer was also deployed on one mast to provide direct estimates of the momentum fluxes. A wave following pressure system, developed by Mark

Donelan from the University of Miami, USA, was deployed during AUSWEX to explore wave-induced stresses and pressure fluctuations in the atmosphere. Mark Donelan and Cyril McCormic operated this system.

It was initially proposed to measure the bottom shear stress with a bottom mounted shear plate. Preliminary tests, however, indicated that the mud bottom of the lake was not suitable for this instrument (a laboratory version is operational). Hence, a high precision traversing system was used to measure vertical velocity profiles in the bottom boundary layer with one of the ADVs, the measurement volume of which was reduced to 1 mm for this purpose.

Full analysis of the data will include a modelling phase, in which the EXACT-NL model of Hasselmann will be used. The model will be forced with the source terms measured at the experimental site and spectral evolution compared with the comprehensive data previously obtained at the Lake George site (*Young, Verhagen, and Khatri*, 1996).

WORK COMPLETED

Data from the Lake George site has now been obtained for more than two years. A database, containing hundreds of hours of wave, wind, air turbulence, sub-surface currents and turbulence, under-water sound, humidity, air and water temperatures and other records, as well as photographic images of the surface, made during the two years of observations prior to AUSWEX, has been prepared, documented and is available on three CDs. About 70 hours of relevant video and hydrophone sound records are available on 24 Super-VHS video tapes.

The joint AUSWEX experiment was carried out from the 14th August to18th September, 1999. The data acquired comprise numerous synchronised records by the wave array, anemometer masts, sonic anemometer, three ADVs located at different levels in the water column, video camera, hydrophone, humidity and temperature probes, as well as by the Dopbeam which was traversed to different depths and by the wave follower. The data, about 2 Gb including those still in archived formats, have been transferred from the field computers to Microsoft and UNIX machines at ADFA and are currently being documented and prepared as a data base. About 45 hours of video and hydrophone sound records were also recorded.

The two photographs below were taken at the Lake George site. The photo on the left shows a general view of the platform with the instrumentation hut in the foreground and the measurement bridge extending to the right. Rigs for deployment of instruments and the anemometer masts are in the background. The second photo shows the bottom of the wave follower shaft, whilst operational: three fingers with pressure probes following a wave crest can be seen. A comprehensive set of photographs showing all facilities and instrumentation at the site, as well as the people, and a video record of the follower in action and a video-sound track of breaking waves, can be viewed on the Lake George Project web site.

 

The data, previously obtained at the Lake George site, have been actively used for scientific research and some results were presented in two papers at the Air-Sea Interface Symposium in Sydney in January, 1999, in two papers at the WISE-6 meeting in Annapolis in March, 1999 and at a number of seminars. Two articles were published in the Proceedings of the ASI Symposium, and two papers have been submitted to the Journal of Physical Oceanography and to the Journal of Geophysical Research.

RESULTS

Of the source/sink functions responsible for wave evolution, the "white-capping" dissipation term is the most poorly understood. Initial analysis of the extensive Lake George data set, started last year, has continued, focusing on the study of the properties of wave breaking. A physical approach, based on the results of numerical simulations by *Banner and Tian*, 1998, provided a basis for the determination of the quantities which determine the breaking statistics. The acoustic signature of the breakers, as recorded by the hydrophone, has been demonstrated and used as an objective measure of breaking. The major findings are:

1. A strong dependence of the breaking probability P on the spectral peak wave steepness ε.
2. The existence of a threshold value of ε, below which no breaking occurs at the spectral peak.
3. A marginal dependence of P on the relative water depth H_s/h, a vertical current shear parameter τ, and wind forcing as measured by the non-dimensional peak frequency ν.
4. A universal relationship for P applicable in both deep and finite depth water.

The concentration on spectral measures of breaking statistics is aimed at implementation in spectral wave prediction models. An article [*Banner, Babanin, and Young*, 1999] and two papers [*Banner, Babanin, and Young*, in review, *Babanin, Young and Banner*, submitted] have been prepared on the subject.

Other analysis of the Lake George data pertained to studies of the bimodality of directional spectra of shoaling waves by means of the high resolution array (*Babanin, Young, and Banner*, 1999). MLM calculated directional spectra show steady bimodal spreading at higher frequencies. The frequency which separates uni-modal and bimodal directional spreading does not correlate with wind parameters but with the peak frequency f_p. These features are in agreement with the computational predictions of

Young, Verhagen, and Banner, 1995. An example of a directional distribution showing bimodal spreading is given in Fig.1 (left).

Properties of the drag coefficient C_{10} for the finite depth waves, and its dependence on breaking, were studied using the anemometer mast records and the breaking detection facilities (presented at the WISE-6 meeting by *Young and Babanin*). Values of the Lake George C_{10} were found to be much enhanced compared to the deep water results, with a very strong correlation between the drag coefficient and the breaking probability P (shown in Fig.1 (right)).

IMPACT/APPLICATION

Results of the field research and parameterization of the source terms will have potential impact in a number of areas.

1).Wind Wave Dynamics. Direct, simultaneous, in situ field measurements of the major source terms together with detailed knowledge of the spectral evolution have not previously been attempted. The results have the potential to provide considerable insight to present understanding of wind wave evolution in finite depth water.

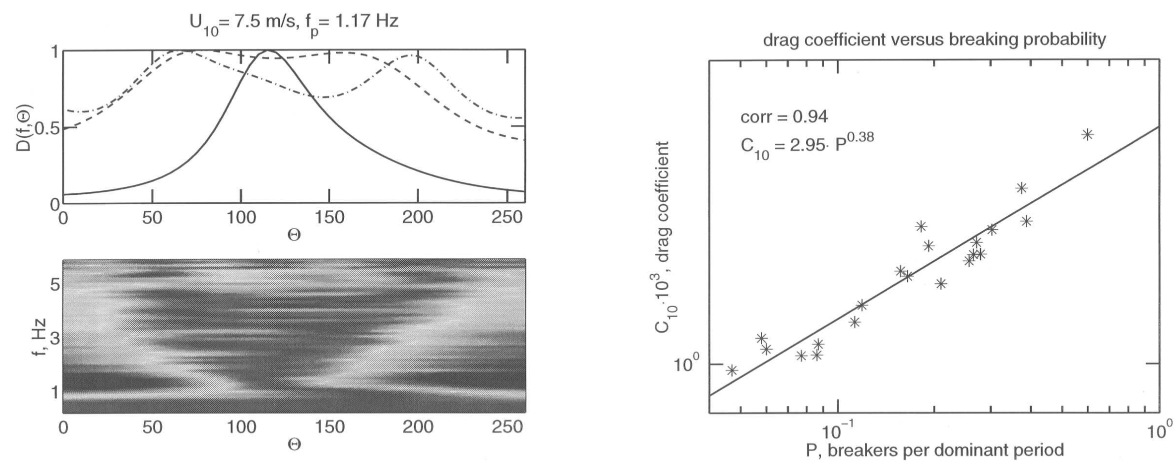

Fig.1. Left: (a) Two dimensional sections of the directional spectrum at frequencies f_p, $2f_p$ (dashed line) and $3f_p$ (dash-dotted line). (b) Shaded image of the directional spreading. Right: 94% correlation dependence of the drag coefficient C_{10} versus the breaking probability P.

2).Wave Modelling. Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water experience. Direct measurement of the source terms in such situations will provide a more appropriate representation for the physical processes in such models. As a result, an enhanced ability to predict nearshore wave conditions should result.

TRANSITIONS

Two groups have used the Lake George facility as a joint effort during AUSWEX, and another two groups intend to use results of the experiment for verification of their theoretical models.

Mark Donelan from the University of Miami installed and successfully operated his wave follower during AUSWEX and will be using the combined data set for analysis of the wind input source function.

Kendall Melville from the Scripps Institute of Oceanography provided his Dopbeam during AUSWEX and will be a part of the data processing and investigation team for studies of sub-surface turbulence and total dissipation of wave energy.

Vladimir Makin from the Royal Dutch Meteorological Institute, De Bilt, The Netherlands plans to provide theoretical interpretation using data of observed distributions of mean and wave-induced stresses by means of his wind-wave coupling model.

Linwood Vincent and Donald Resio of CERC are combining the high resolution spectra measured at the Lake George site with other finite depth data to study the detailed form of the finite depth wind wave spectrum.

RELATED PROJECTS

This project is coordinated with the other DRI experiments planned for Duck, North Carolina. As the experimental site provides good control over the environmental parameters, it is hoped the experiment may well fill some of the gaps in the larger scale, open ocean DRI measurements.

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